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Explaining the role of incumbent utilities in sustainable energy transitions: A case study of the smart grid development in China

Abstract

Smart grids (SGs) have been widely recognized as an enabling technology for delivering sustainable energy transitions. Such transitions have given rise to more complex government-utility-consumer relationships. However, these stakeholder relationships remain largely under-researched. This paper critically examines and explains the role of incumbent utilities in sustainable energy transitions, using SG developments in China as a case study. We have three major findings. First, China has developed an incumbent-led model for deploying SGs. Second, two incumbents, the major-state-owned grid companies, act as enablers of SG deployment. They are strategic first-movers and infrastructure builders of SGs. They have also developed five types of networks as they increasingly reach out to other state actors, businesses, and electricity consumers. Thirdly, these two grid companies also act as a fundamental block to structural changes in socio-technical regimes. Disincentives to these large existing grid companies coupled with excessive reliance on them to provide public goods have resulted in major weaknesses in China's incumbent-led model. Our findings have clear policy implications. Innovation in regulating incumbents is needed in order to provide sufficient regulatory incentives for advancing SG developments in China.

Keywords
Smart grids, incumbent utilities, governance, socio-technical transitions, distributed energy sources, China

1. Introduction

SGs are advanced technologies based on the intensive use of IT and communication technologies over the entire generation, transmission and distribution systems of the electricity sector. They are generally recognized as an enabling technology for achieving sustainable energy transitions (Liu, 2013; Mamo *et al.*, 2009). SGs have the potential to support a broad range of advanced energy technologies on both the supply-side (e.g. large scale integration of renewable energy and distributed energy sources) and demand-side of energy management (e.g. demand responses) (IEA, 2011). Although SGs may be defined and deployed in various ways in different contexts, they have been increasingly developed worldwide since the mid-2000s, most notably in the US, the UK, Italy, Japan, and South Korea (Energy and Climate Change Committee, 2015; Executive Office, 2011; Mah *et al.*, 2012; Mah *et al.*, 2013).

China is a late-comer in the context of SG developments. A three-stage SG plan announced by the state-owned State Grid Corporation of China (SGCC) in 2009 is widely regarded as a key milestone marking the beginning of SG developments in China. Since then, China has embarked on its SG developments which are in many respects atypical when compared with SG developments elsewhere. First, as a late-comer, China has the potential to leapfrog the deployment process for SGs. In 2010, China already surpassed the US in total SG expenditures, with costs of the nationwide grid upgrade projects estimated to be US$100 billion through 2020 (EIA/SAIC, 2011). Second, China's SG initiatives have largely focused on high-voltage transmission networks (Liu, 2013). In contrast, the US approach has focused on energy system resilience and reliability (Connor *et al.*, 2014) while the Japanese model is business-driven and community-based (Mah *et al.*, 2013). Another notable feature of China's SG developments is the prominence of the two large state-owned monopolized grid operators: the State Grid Corporation of China (SGCC) and China Southern Power Grid Co. Ltd. (CSG). These two grid operators, which account for 88 percent and 17 percent of national power consumption respectively (Brunekreeft *et al.*, 2015), are the driving forces and first movers in this industry by mobilizing massive investment in grid enhancement and rolling out smart meter installations (Zpryme, 2011).

Given the key role of the two state-owned grid companies, this paper aims to examine the role of incumbent utilities from the perspective of governance for sustainable energy transitions. We investigate the extent to which as well as how and why these two incumbent utilities have facilitated or impeded SG deployment in an increasingly dynamic stakeholder landscape in China.

This paper is a qualitative case study of China's SG developments. Our findings are derived from desktop research, semi-structured face-to-face interviews, and field visits. Some 21 interviewees were interviewed in 14 meetings which took place in Beijing, Tianjin, and Guangdong between 2014 and 2017. The interviewees were carefully selected informants and stakeholders holding roles, positions, or status in organisations, social networks, or communities of the political system and were therefore knowledgeable about the issues studied (Johnson, 1990). They included (1) a senior government official and senior researchers from the National Development and Reform Commission (NDRC), (2) senior researchers from various research institutes of NDRC and the two grid companies, (3) executives of a local grid companies, (4) academics, (5) energy consultants, and (6) two senior executives of solar PV companies.

All the interviews were audio-recorded and transcribed. Some follow-up email correspondence and telephone calls were made to request supplementary information and updated data. Not all interviews were cited, but those not cited are still useful for this study as they provide important contextual information. As some interviewees agreed to be interviewed only anonymously, this study indicates interviewees by number. The first two letters indicate the location (BJ for Beijing, TJ for Tianjin, and GD for Guangdong), the two digits indicate the interview numbers, and this is followed by the year of the interviews. The list of interviews is provided in the appendix.

The rest of the paper is organized into four sections. The next section develops a theoretical perspective that focuses on the linkages between the concepts of socio-technical transitions and stakeholder relationships. Our conceptual framework is then used to guide our analysis of the case study. The discussion moves on to examine the characteristics of SG developments in China. We then critically analyze the roles of the two grid companies as facilitators of and/or barriers to SG deployment as government-incumbent-consumer relations evolve. The final section of the paper offers some concluding thoughts and policy recommendations.

2. Understanding the roles of incumbents in SG deployment: A theoretical discussion

2.1. A socio-technical transition perspective

SGs require a variety of innovation nodes covering both supply-side and demand-side energy initiatives. A substantial body of literature has shed light on the technological aspects of these innovations. For example, Gellings's (2009) work has instructively specified ten major nodes of technological innovations. These include distributed generation, energy storage, building systems, efficient appliances and devices, sensors, power electronics and controls, communication, and computational ability.

Much less studied are the socio-economic and political dimensions of these nodes of innovation (Bigerna *et al.*, 2015). The socio-technical transition perspective, as an emerging theme of the SG literature, sheds important light on the complex stakeholder relationships between government, incumbents, new market entrants, and electricity consumers in sophisticated, large socio-technical systems such as electricity systems (Erlinghagen and Markard, 2012; Mah *et al.*, 2013). This theme of the literature argues that path-dependency or the "lock-in" effect of established energy technology has been reinforced in energy systems by their own ideas, culture, user practices and technical competence that have developed over time (Sovacool, 2009; Szatow *et al.*, 2012). Fundamental regime changes that threaten the vested interests of incumbents are therefore difficult to achieve (Geels, 2005; Szatow *et al.*, 2012).

2.2. A stakeholder perspective

This socio-technical transition perspective argues that SG deployment requires new and innovative approaches to governing stakeholder relationships. To fully realize the benefits that SGs can offer, traditional top-down, technocratic governance systems need to be transformed to accommodate more new actors (such as renewable energy suppliers) and two-way utility-consumer relationships (as "prosumers" can sell surplus renewable electricity to grid companies, and well-informed electricity consumers could contribute to demand response programmes) (Erlinghagen and Markard, 2012; Grünewald *et al.*, 2012).

This theme in the SG literature distinguishes between two key types of actors in the electricity sector: regime actors (or incumbents) and niche actors (or new entrants) (Erlinghagen & Markard, 2012). This literature focuses on the influence of regime actors in innovation processes, niche actors as origins of radical innovations, the weakening of path dependencies, and the scaling up of processes of new energy technology deployment (Erlinghagen & Markard, 2012; Markard & Truffer, 2006).

Regime actors generally refer to incumbents in the sector. They are established firms (Erlinghagen & Markard, 2012). Electric utilities, which generate, transmit, or distribute electricity and recover the costs through a regulatory framework have the tendency to become incumbents because utilities, particularly grid operators, are a natural monopoly (DOE, 2008; Governor of NYS, 2014). These incumbents themselves have a strong culture, including their beliefs and dominant logic (Chesbrough & Rosenbloom, 2002), and are highly intertwined with the core technologies, business models and user-practices of the regime (Erlinghagen & Markard, 2012).

Niche actors generally refer to new entrants that have entered the sector (Erlinghagen & Markard, 2012) and which are generally smaller, and more innovative (Mitchell & Woodman, 2010). Energy services companies (Liu *et al.*, 2013), the ICT sector (such as mobile and fixed carrier businesses) (Erlinghagen & Markard, 2012), property developers (Szatow et al., 2012), and even social housing corporations (e.g. in the Netherlands) (IEA-RETD, 2013), are examples of new entrants.

The distinction between incumbents and new entrants is of scholarly importance because it sheds light on a key debate, namely: can major breakthroughs in socio-technical regimes come from incumbents or do these have to come from new market participants?

The literature presents a mixed picture of such incumbent-challenger relationships. On the one hand, some argue that incumbent utilities are the last place where innovations including those involving stakeholder relationships can be expected to occur (Lehr, 2013). Important SG applications, including high penetration of distributed energy (DE) generation and extensive use of demand response programmes require more fragmented and decentralized energy markets (Mah *et al.*, 2012). Incumbents are also required to manage new utility-consumer relationships as consumers can both produce and consume electricity and proactively take part in demand response programmes (ten Heuvelhof & Weijnen, 2013). However, utilities, particularly those that are monopolies and state-protected, have reduced monopoly power as SGs develop, and thus may have little or no incentive to contribute to regime shifts (Agrell *et al.*, 2013; Erlinghagen & Markard, 2012; Markard & Truffer, 2006; ten Heuvelhof & Weijnen, 2013). The literature highlights this problem of utility disincentives, and argues that incumbents lack incentives to innovate, minimize costs, or to take risks while having strong incentives to prevent market entry by competitors (Lehr, 2013; Mah *et al.*, 2014; Martinot & McDoom, 2000). The dominance of incumbent business interests in the transition may achieve short-term gains in areas such as GHG emission reductions and technological learning, but it has major limitations in achieving the institutional or cultural changes that are also required for delivering sustainable energy transitions (Laes *et al.*, 2014).

On the other hand however, some contributions highlight the unique position of incumbents in taking a proactive role in such energy innovations. Unlike private entities which are generally profit-maximizers, state-owned/controlled utilities may be motivated by strategic considerations rather than short-term economic benefits to support energy innovation experimentation (Radcliffe *et al.*, 2014). Incumbent utilities also exhibit unique advantages, or structural advantages, over challengers, which explains why they capture first-mover advantages in developing new energy options. These advantages include access to resources (Markard & Truffer, 2006), the establishment of strategic alliances, resilience to regulatory and market risks (Radcliffe *et al.*, 2014), pre-existing competencies in infrastructural planning, asset management and operation (Curtis & Khare, 2004), and customer loyalty (Curtis & Khare, 2004).

In relation to the potential of niche actors in creating radical innovations that may challenge established energy regimes, the literature also presents a mixed picture (Geels, 2004). The literature suggests that while new entrants may deviate radically from existing business practices, they often lack financial resources, technical skills, and political influence to initiate large-scale system change (Shomali & Pinkse, 2015; Zhang *et al.*, 2014).

2.3. Global overview and the gaps in the Chinese context

SG deployment has been taken place primarily in Europe and the US with massive investment motivated by accommodating large-scale renewable energy sources and grid enhancements (ten Heuvelhof & Weijnen, 2013). Emerging economies such as China and India have also invested heavily in transmission technologies (Bigerna *et al.*, 2015; ten Heuvelhof & Weijnen, 2013). The smart grid literature indicates that the adoption of SG technologies varies markedly across countries, depending on many factors including government policies, regulatory incentives, and technology experience levels within utilities (Bigerna *et al.*, 2015; ten Heuvelhof & Weijnen, 2013).

Given the prominent roles of regime actors in energy transitions, a growing body of empirical studies has exposed how incumbent utilities interact differently with other stakeholders in the transition context. For example, Lehr (2013), Markard & Truffer (2006) and Martinot & McDoom (2000) discuss the centrality of incumbent utilities in the effective implementation of low carbon mechanisms, and how they become prime movers to push innovation. In the UK, studies have found that major companies responded well to low-carbon policies, and are a key to the effectiveness of the UK renewable obligation (Martinot & McDoom, 2000). In France, the state-owned Électricité de France (EDF) has been the driving force for SG initiatives (Mamo, 2010). In some states of the US where electricity markets have been liberalized, incumbent utilities are expected to act as distribution network operators, or smart integrators/orchestrators who manage distributed energy sources (Governor of NYS, 2014; Lehr, 2013). However, unlike the situation in the UK or France, incumbents in Germany were found to be the laggards in investing in renewable energy, leaving small challenger actors shaping the development pathways of renewables (Wassermann *et al.*, 2015).

Some empirical studies have focused on the role of new market players, or challengers in initiating forces of change which may converge, accumulate, and subsequently challenge existing socio-technical energy regimes (Markard & Truffer, 2006). While the success of these challengers is still to be carefully evaluated through empirical analysis (IEA-RETD, 2013; Raven, 2006; Szatow et al., 2012), work by Szatow *et al*. (2012) explains why these newcomers have such potential. In their study on Australian electric power systems and DE, the authors documented the ways in which a property company utilized its pre-existing resources and networks (e.g. access to finance), expanded its business functions to become an integrated energy service provider, and subsequently competed with the incumbents (Szatow *et al.*, 2012).

Our focus on incumbent utilities and China is of academic significance. Most literature on SG developments is located in the West. The literature on SGs in China has been limited, focusing mostly on the technological and economic aspects (see, for example, Wang *et al.*, 2016). The discussion on socio-technical regimes and stakeholder relationships in the Chinese context is particularly limited (see, for example, Mah *et al.* (2012); Yuan *et al.* (2012)).

The Chinese literature on the broader field of energy has however presented a mixed picture of the role of incumbent utilities. The two grid operators and the five major state-owned power generation companies (the Big Five) are found to be the key to the implementation of major energy policies (Mah & Hills, 2008; Zhang *et al.*, 2016). However, on the other hand, they may also be a major barrier to new energy technologies such as distributed energy generation (Liu *et al.*, 2013). The size and monopoly power of the grid operators also makes regulation difficult (Brunekreeft *et al.*, 2015). The role of Chinese incumbents and how they interact with new market players, and how such interactions impact on SG developments in emerging market contexts need to be better understood.

2.4. An analytical perspective and research questions

In our analytical perspective we look beyond a polarized debate, in which incumbent utilities are understood to act as either a major contributor or a major barrier to sustainable energy transitions. We aim to develop a deeper understanding of the extent to which, where, under what conditions, and why incumbent utilities may facilitate or impede sustainable energy transitions in a rapidly evolving stakeholder landscape. Our conceptual perspective will guide us to focus our analysis on the existence of both incumbent advantages and disincentives, and the associated impacts on SG deployment in China. In so doing, we address the following questions:

i. What are the characteristics of SG developments in China?
ii. In the context of an evolving stakeholder landscape, how do the incumbent grid companies respond to SG developments? How do they exercise incumbent advantages for SG deployment? How do they act as barriers to SG deployment?
iii. Why do the incumbents respond in the observed ways?
iv. What are the outcomes in terms of China's model of SG development? To what extent was this model effective in achieving the scaling up of SG deployment?

3. SGs in China: Motivations, major policy initiatives, and China's partial electricity market reforms as a contextual background

China, as the world's largest energy consumer and greenhouse gas emitter (C2ES, 2015; EIA, 2016), has been motivated to develop SGs mainly to improve reliability of energy supply, facilitate integration of renewable energy, and enable extensive deployment of demand response programmes (Brunekreeft *et al.*, 2015; Zpryme, 2011; Interview BJ/04/2014). In addition, SGs present a cost-effective energy option through the development of energy markets, as well as energy products and services

(Interview BJ/04/2014).

While some countries have introduced national SG plans or roadmaps (e.g. South Korea) (Mah *et al.*, 2012), it is important to note that the Chinese government has relied on a loose policy framework and an incumbent-led approach to guide SG developments. As yet, there is not a national plan for SGs.

The first major initiative on SG in China was not launched by the Chinese government, but by the SGCC. In 2009, the Corporation announced its 3-Stage SG plan, which is widely regarded as a milestone in SG developments in China. This was followed by CSG's announcement of its 2-Stage SG plan in 2010. Since then, these industry-level initiatives have been gradually elevated to a strategic national priority (Hart, 2011). In 2010, the then Chinese Premier Wen Jiabao announced that construction of a SG was a national priority, with completion planned for 2020 (EIA/SAIC, 2011). SG was then included in the 12th FYP for National Economic and Social Development (2011-2015), and further highlighted as one of the key national strategies for delivering energy transitions in the 13th FYP which was endorsed in March 2016 (Yuan *et al.*, 2014). Two important policies announced by the NDRC in 2012 and 2015 respectively are regarded as being instrumental in strengthening the policy framework for SGs. The 2012 NDRC special plan on SG provides policy guidelines on industrialization, standard systems, and demonstration projects of SG technologies. The 2015 NDRC document reaffirms the 2020 target to establish a SG system, and outlines a relatively comprehensive strategy that extends policy support in the areas of IT systems, economic viability, international standardization and new business model development (NDRC & NEA, 2015) (Table 1). These five-year plans and NDRC documents are further supported by a large number of SG-related policies at both national and local levels. These policies cover a broad range of energy technologies, from renewable energy, energy efficiency, micro-grids, to electric vehicles and green industries.

[Insert Table 1 about here]

The development of SGs in China has been strongly influenced by on-going electricity market reforms. As one of the major outcomes of the 2002 electricity market reform, two state-owned grid companies and five power generation companies were established as the current incarnation of the State Power Corporation of China – which was a state-owned, vertically integrated monopoly that owned 90 percent of China's grid assets and 46 percent of power generation assets (Mah & Hills, 2008). So far, market competition has been introduced only to the power generation segment. In this stalled state of reform, the two grid operators have remained geographical monopolies. SGCC and CSG control electricity transmission, distribution, and retailing in their respective regions (Figure 1 and Table 2). They have ministry-like status, and have remained large and influential (Brunekreeft *et al.*, 2015; RAP, 2008; Interview BJ/03/2014). This dominance to a large extent explains their prominence in China's SG initiatives.

[Insert Figure 1 about here]

[Insert Table 2 about here]

4. Findings and discussion

4.1 An incumbent-led model of SG development in China

SGs in China have developed differently from those in other countries. This study found that a defining feature of the Chinese approach is the central role played by the two grid operators, SGCC and CSG. In China's incumbent-led model, the two grid operators were the prime movers and driving force of many SG developments. SGCC has been regarded as the main proponent of SGs (EIA/SAIC, 2011; Zpryme, 2011). CSG has played a secondary role in the development of SG technologies, letting SGCC to take the lead (Zpryme, 2011). However, both SGCC and CSG have played a decisive role in the construction of SG in China (World Energy Council, 2012). The 3-Stage SG Plan (2009-2020) announced by SGCC in 2009 and the 2-stage SG Plan announced by CSG in 2010 have set the direction as well as the timeline for SG developments for the nation.

What, then, are the motivations of the two grid companies to develop SGs? Political obligations coupled with social responsibility appear to be the primary motivation. SGCC, which serves over 1.1 billion people and accounts for 83 percent of national electricity consumption, believes that it needs to take the lead in developing SGs or China will lag behind international standards for power system development (Interview BJ/07/2014; Xiao, 2013). In addition, the two monopolies have also been motivated by material benefits: through strengthening their own grids as well as empowering a supporting domestic equipment industry, particularly for the smart meter market (Schleicher-Tappeser, 2012). It is also noteworthy that the two grid companies focus on different aspects of SG development: SGCC focuses on ultra-high voltage transmission systems while CSG places more attention on high penetration of distributed energy sources and demand-side management (Interviews BJ/03/2014; GD/03/2015; CSG, 2015c).

4.2. Major roles of the two grid companies in SG development

Our case study demonstrates that the two grid companies have actively responded to the potential opportunities offered by SG developments. They appear to have played five important roles in this incumbent-led model. They act as infrastructure planners and builders of SGs, transmission network operators, regulators through standard-setting, technology developers, and energy services providers.

(1) As SG infrastructure planners and builders

The two companies have created SG infrastructure through mobilizing massive investment in grid enhancement and smart meter installations. During the 12th Five-Year Period (2011-2015), SGCC was expected to invest RMB 1.6 trillion in grid expansion and upgrades, with RMB 286 billion – approximately 18 percent - designated for SG projects. A substantial part of this early investment has been allocated for smart meter deployment, in order to realize its target to deploy 300 million meters by 2015 and up to 380 million meters by 2020 (Alejandro *et al.*, 2014; Stern, 2015). CSG was also expected to invest about RMB 66 billion in grid expansion and updates, with a target of reaching a 100% smart meter rollout by 2020 (Interview GD/03/2015; CSG, 2015a).

In terms of actual smart meter rollouts, China is already the world's largest market. Smart meter installations are expected to grow from 139 million units in 2012 to 377 million units by 2020, reaching 74 percent market penetration (Alejandro *et al.*, 2014). CSG has however lagged behind in smart meter installation. At present about some 1.3 million of the 3.5 million electric meters installed by CSG's end-users are "smart meters", which have the ability of two-way communication between utilities and end-users, a penetration rate of only 37 percent (Interview GD/03/2015).

(2) As distribution network operators

The two grid monopolies have increasingly expanded their functions as distribution network operators. With increasing regulation of grid access and renewable pricing policies (ERI, 2013), SGCC and CSG are mandated to provide grid connection and electricity metering free-of-charge (Liang, 2015). SGCC provided grid access services to 1,052 DE projects, involving a total installed capacity of 2,650 MW and 6,936 consumers by the end of 2014 (SGCC, 2015). CSG provided grid access services to renewable projects with a total installed capacity of 16,214 MW by end 2015; these include distributed photovoltaic (PV) projects and utility-scale PV of an installed capacity of 819 MW and 1,500 MW respectively (Interview GD/03/2015, supplemented with updated data provided through email correspondence). In addition, the two grid companies provide subsidies on behalf of the national government. For example, a 0.42 yuan/kWh subsidy has been provided for electricity produced from distributed PV facilities (Liang, 2015). On-grid prices for coal-fired electricity across provinces and direct-controlled municipalities range from RMB 0.26 to 0.45 (NDRC, 2015).

(3) As regulators – through standard setting

The two grid companies have also introduced SG-related regulations, which are mostly related to technical requirements for technologies such as distributed energy generation. SGCC has published 166 enterprise-class standards, as 42 national and industry standards for DE generation were developed and amended under contract (Liu, 2013). One of the most significant regulations introduced by SGCC was introduced in 2012 and provides free-of-charge connection services for DPV electricity producers who are located close to customers so as to encourage local electricity consumption first (SGCC, 2012). This regulation was symbolic because it demonstrated explicit support from SGCC for grid access and connection of DE (SGCC, 2012; Interview BJ/01/2014).

(4) As technology developers and knowledge creators

SGCC and CSG have played an important role as technology developers and knowledge creators primarily through conducting a large number of SG pilot projects (Interviews BJ/07/2014; GD/03/2015). SGCC alone has implemented about 230 SG pilot projects to solve technical issues, test designs, and develop management systems in the first stage of its SG plan (between 2009-2010) (Zpryme, 2011). In addition to technology studies, it also conducted market (e.g. the potential new markets) and policy studies (e.g. tariff reforms) (Interviews BJ/04/2014; GD/01/2015; Metering China, 2016).

(5) As new energy service providers

Although the core business of the two grid companies has remained in the traditional technologies, they have moved into new service areas in response to the opportunities offered by SG technologies. SGCC, for example, has conducted studies exploring options for new business models. In one of its case studies of business model innovation, SGCC explored the possibility of providing value-added services associated with the use of power optical fibre cable to its clients in Shanghai (Interview BJ/07/2014; Liu, 2013). CSG has also set up a subsidiary providing energy audit services to clients (CSG, 2015b).

4.3. Achievements and limitations of China's incumbent-led model

To what extent, then, is China's model for SG developments effective? This study adopts a refined smart grid maturity model developed by Mah *et al.* (2013) to evaluate SG transitional processes. Based on this model, which distinguishes between three orders of transitional process, our study found that SG development in China has yet to progress beyond the first-order of SG maturity, and hence has not been able to realize higher order benefits (Table 3).

Under this incumbent-led model, China has realized some major achievements in smart meter installation and in the expansion of ultra-high voltage transmission systems. The two grid companies have also carried out a large number of experimental projects involving SG technologies.

Such achievements, however, must be interpreted with caution. The Chinese model has revealed some major limitations. There has been a lack of structural change in China's electricity sector. The electricity sector has remained fossil fuel-based, and is still dominated by existing power utilities. Higher-order potential benefits offered by SGs, such as the extensive use of demand response programmes and high penetration of renewable energy have not yet materialized in at least four important ways (Table 3):

- Smart meter deployment: smart meter installation reached an 80 percent penetration rate but the functional benefits of web-based data visualization which can enable two-way utility-consumers communication have not been realized (Interview BJ/01/2014; Stern, 2015).

- Demand response (DR) programmes: DR programmes could be enabled by automatic control technology and decision-support technology but at present DR programmes have been largely limited to the pilot scale. Dynamic pricing, which is essential for effective DR programmes, has been emerging, but remains at a very early stage of development (Interview GD/07/2016; Stern, 2015).

- Distributed energy (DE) generation: the operational benefits of SG technologies to enable high penetration of DE have not materialized. DE sources, including distributed PV, small hydropower, distributed wind generation, and natural gas distributed energy (Zeng *et al.*, 2015a, b), totaled 34.36 GW and contributed only approximately 3 percent of the national total installed capacity (in 2012)(CNREC, 2013b; SGCC, Dec 10, 2012).
- Business model (BM) innovation: BM developments for supporting new products, services, and markets that relate to SG technologies have remained limited in scale and under-developed (Interviews BJ/04/2014, GD/10/2017; Kostka & Shin, 2013; NEA, 2014).

[Insert Table 3 about here]

[Insert Figure 2 about here]

[Insert Figure 3 about here]

4.4. Incumbents as enablers and as barriers: What explains this?

We argue that China's two grid operators have access to several incumbent advantages that are available to them only by virtue of their state-owned, monopoly position. These advantages include internal capabilities and external networks and have enabled them to act as the driving force for SGs. On the other hand, the two companies have acted as a fundamental block to structural changes in the socio-technical regimes that are needed for major SG developments. Incumbent disincentives and excessive reliance on them to provide public goods are some of those problems that have resulted in major weaknesses in China's model. We also found that the complexity of the emerging stakeholder relationships can in part explain the mixed outcomes of SG deployments.

4.4.1. The advantages of the incumbent utilities

(a) Internal capabilities: Financial strengths and technical expertise

The first key advantage enjoyed by the two grid companies relates to their internal capabilities. SGCC and CSG possess financial strengths and technical expertise. With their origins in China's highly centralized planned economy in which massive resources can be mobilized effectively (but not necessarily efficiently) for specific national goals (Ma & He, 2008), they were able to mobilize the massive investment required for grid expansion and smart meter installation. During the 12^{th} Five-year Period (2011-2015), SGCC reportedly invested RMB 1.6 trillion in grid expansion and upgrades. A substantial proportion of this early investment was planned for smart meter deployment (Stern, 2015). CSG reportedly invested RMB 66 billion in grid projects (CSG, 2015a).

In addition to their financial strength, the two companies also possess relatively high technical expertise and innovation capacity. As the monopoly grid operators for the country, the two companies possess the pre-existing technological competence in planning, financing, constructing, as well as managing major grid infrastructure works and other major energy facilitates such as power plants (Interview BJ/03/2014; Xiao, 2013). Their technological expertise has also allowed them to take the lead in developing technical standards relating to SGs (Interviews BJ/04/2014; GD/01/2015; Metering China, 2016).

It is important to note that the in-house research institutes of SGCC and CSG are important institutions that have strengthened their technological expertise and innovation capacity (Interview BJ/03/2014; Xiao, 2013). Both SGCC and CSG have set up SG-specific research divisions. SGCC's State Grid Smart Grid Research Institute has been reorganized and became the Internet Global Energy Research Institute in February 2016 (SGCC, 2016). CSG's Smart Grid Research Institute is one of the seven institutes of the 292-staff Electric Power Research institute (Interview GD/01/2015; CSG, 2015c).

(b) External networks in an evolving stakeholder landscape

Another advantage of SGCC and CSG arises from their extensive networks that have emerged amidst an increasingly dynamic stakeholder landscape. SG developments in China have provided opportunities for the two incumbents to reach out to a wide range of other stakeholders. These include: national and local governments, power generation companies, decentralised energy suppliers, technology providers, components manufacturers and suppliers, ICT service providers, energy services companies, state-owned banks, universities, and electricity consumers.

Using Geels's (2004) framework, this study has revealed that the two grid companies have established at least five major types of networks, political networks, financial networks, industrial networks, research networks, and utility-end user networks with these stakeholders as shown in *Figure 4*.

In terms of policy networks, because of their ministry-like status, SGCC and CSG possess strong policy linkages at both the central and local government levels. They have played an important role in providing policy recommendations to government, in implementing national and local policies, and conducting SG and DE pilot projects. It is important to note that, *complementarities*, either in terms of resources or expertise, are a key to sustaining such political linkages. For example, because of SGCC's advantage of its access to a great amount of detailed consumption data, local governments have the motivation to collaborate with SGCC to conduct SG-related studies (Interview BJ/04/2014).

The two incumbents' financial networks have been reinforced by their linkages with state-owned banks. Chinese state-owned enterprises (SOEs) can access low-interest loans provided by state-owned banks so they have greater opportunities to mobilize sufficient capital for massive projects. They may also be able to sustain operating losses over time (Santalco, 2012). Such financial linkages have become critical in helping the incumbents overcome some of the economic barriers to SG deployment, including high upfront costs, long pay-back periods and market risks. In contrast, high entry costs have deterred private enterprises from entering the Chinese SG market (Interviews BJ/02/2014; BJ/05/2014; BJ/07/2014; GD/10/2017).

In addition, SGCC and CSG have also developed industry networks with generation companies, and various technology providers, components manufacturers, and suppliers. Both grid companies have been expanding their business portfolios across the value chain. SGCC has taken over domestic engineering firms and leading electric power equipment manufacturers (Brunekreeft *et al.*, 2015).

In addition to their in-house research capacity, the two grid companies have developed external research networks through collaboration with universities and other research institutes in many of their SG pilot projects (Interviews TJ/01/2014; TJ/02/2014; Xiao, 2013). Such enterprise-university research networks have their roots in the decentralization of R&D responsibilities that was first introduced in the early 1980s by the Chinese government. Since then, horizontal ties between power utilities, universities, and research institutes have been strengthened and incentivized (Mah & Hills, 2014).

In terms of utility-consumer network, the pre-existing customer loyalty in the power market seems to be critical. Because the two grid companies are geographical monopolies, electricity consumers have no choice of energy suppliers, and they tend to be the followers and seldom challenge utilities for any technological or policy changes to be introduced (Interviews BJ/07/2014; GD/01/2015; GD/03/2015). While smart meter installations have been one of the major causes of smart meter backlash in a number of western economies (Mah *et al.*, 2011a), Chinese electricity consumers are generally are less skeptical when SGCC and CSG's technicians install smart meters for households (Interviews BJ/07/2014; GD/01/2015; GD/03/2015). The trust relationships between grid companies and household end-users in China can at least partly explain the relatively rapid deployment of smart meters in the country.

[Insert Figure 4 about here]

4.4.2. Major problems associated with the incumbents

The two grid companies have however also acted as a barrier to SG developments. Four key problems have resulted in major weaknesses in China's model of SG development.

The first involves disincentives. Although the two grid companies have increasingly assumed the role of distribution system operators, such changes have remained limited. At present, there is no pricing system that allows them to recover the costs of ancillary services, such as voltage support services (Zeng *et al.*, 2015a). Extra costs may also be incurred by a grid company if solar electricity from distributed sources is of sub-optimal quality because a grid company may need to invest more to address these technical challenges (Interview GD/07/2016). To a large extent because of the lack of compensation mechanisms, SGCC and CSG have very limited incentives to facilitate a high penetration of distributed energy sources into their grids.

The second problem relates to inertia. SGCC and CSG are resistant to structural change in the power sector. Their utility's logic centres on energy security and reliability. They regard technological innovation, cost reduction and profit maximizing as lesser concerns (Interviews BJ/03/2014; BJ/04/2014; Zhang *et al.*, 2017). In addition, forces for change from new market players have remained limited. In addition, electricity end-users in China generally do not have a choice of energy suppliers, and grid operators do not need to take end-users' needs for new energy products and services into account to a large extent (Interviews BJ/01/2014; BJ/02/2014; Zhang *et al.*, 2017).

The third problem is the existence of a vicious cycle due to an excessive concentration of multiple roles in the two grid companies. Apart from managing transmission, distribution, and retailing in the power sector, these incumbents have also taken the lead in developing technical standards for SG technologies. The critical importance of standard-setting and other functions that are in effect public goods in sustainable energy transitions has been extensively discussed (see, for example, Mah & Hills, 2014; Martinot & McDoom, 2000). Codes, standards, and certification can reduce commercial and purchase risks as well as negative perceptions of technology performance (Martinot & McDoom, 2000). Certification and testing agencies can allow manufacturers to easily verify compliance with standards and provide purchasers with performance assurance (Martinot & McDoom, 2000).

In China, standard-setting for SG developments has been an industry-led process. However, senior government officials and experts in the field indicate that the development of technical standards has been too slow, and is unlikely to be able to support significant uptake of, for example, DE generation in China (Interviews

BJ/04/2014; GD/07/2016). One good example to illustrate this problem is that following the SGCC's introduction of policies regulating grid access to distributed energy sources, it took CSG another two years to formulate similar rules in 2014 (Interview BJ/07/2014; ERI, 2013). The incumbents' disincentives and inertia alongside the government's reliance on the grid companies to set standards have tended to reinforce the status quo rather than to promote socio-technical transitions.

The fourth problem is a lack of resources and expertise to develop new energy products and services. While the two grid companies are competent in developing and managing large-scale energy projects, they generally lack the competence and resources to develop new energy products and services (Interviews BJ/02/2014; BJ/07/2014; GD/03/2015; GD/08/2017). Energy services companies have been emerging in the Chinese market but the industry is still underdeveloped (Interview GD/08/2017; Zhang *et al.*, 2017).

4.4.3. Some innovations in stakeholder relationships but weak linkages exist

The mixed outcomes of China's incumbent-led model can also be explained by the complexity of the emerging stakeholder relationships. On the one hand, some new relationships have enhanced SG deployments; on the other hand, some weak linkages have constrained China from progressing towards the third-order of SG maturity (*Figure 4*). Our case study has found that three changes in stakeholder relationships are significant.

First, in terms of government-utility relationships, the expansion of the role of government in regulating the grid companies was found to be conducive to SG developments. Through the introduction of a growing body of regulations, the government has created regulatory incentives for the two grid companies to transit from their traditional business models to new business models that place more emphasis on the roles of distribution system operators.

Second, it is important to note that the intensity of such industrial linkages varied between the two grid companies and different types of industrial actors: strong linkages are found between the grid companies and their strategic partners, while weak linkages exist between them and new market players (indicated by the bold and thin arrows in *Figure 4*). Both grid companies have developed strategic alliances with technology providers and component manufacturers which are either their subsidiaries or long-term business partners (Interview BJ/02/2014). Such strategic alliances are likely to enable the grid operators to better manage costs, as well as effecting a stabilization process which can reduce market risks (Radcliffe *et al.*, 2014). In addition to expanding their business portfolio across the value chain, SGCC and CSG have also maintained close relationships with state-owned power generation companies in order to deliver national SG-related policies, including a non-fossil fuel target of 15% by 2020 (NDRC & NEA, 2015; Interview GD/08/2017). In contrast, the linkages with new market players such as entrepreneurial firms, energy services companies, ICT service providers, and third-party standardization organizations have remained weak (Interviews TJ/03/2014; GD/08/2017). Private property sectors, for example, have been increasingly recognized in the West as a critical new energy service providers which can optimize the mix of local and centralized energy generation technologies (Szatow et al., 2012). Such business models are emerging in specific property projects in China, such as one in the Sino-Singapore Tianjin Eco-city, but generally have remained in their early stages of developments (Interviews BU/04/2014; TJ/03/2014).

Third, the complexity of the emerging utility-consumer relationships has also limited the market scale of SG technologies in China. In some important senses, the linkages between the grid companies and their consumers have remained weak. It has been increasingly recognized that public and market support is crucial to SG deployment (Mah *et al.*, 2012). However, our case study has shed light on the fact that smart meter installation is not sufficient to fully realize the potential benefits that SG technologies could offer. Extensive and intensive interactions between price-sensitive, well-informed electricity consumers and utility companies are also needed to be developed in order to broaden energy technology choices and encourage more energy savings (World Energy Council, 2012). Although smart meter installation reached an 80 percent penetration rate in China, electricity consumers have remained to be passive end-users in the absence of effective dynamic pricing and web-based data visualization systems. There are some price-sensitive consumers engaged in dynamic pricing pilot projects (Interviews BJ/07/2014; GD/03/2015). However demand-response programmes have remained limited in scale and impacts (Interviews BJ/03/2014; GD/08/2017; GD/10/2017).

5. Conclusions and policy recommendations

Based on this case study of SG developments in China, we have made three major theoretical contributions to the literature on governance for sustainable energy transitions. Firstly, we have characterized the Chinese model of SG development as an incumbent-led approach. This finding enriches our understanding of the variety of sustainable energy transition pathways that have been emerging (Laes *et al.*, 2014; Mah *et al.*, 2012; Mah *et al.*, 2013).

Secondly, we have contributed to the literature by providing a more precise mapping of the roles of incumbent utilities in sustainable energy transitions. We specified the five major roles played by the two monopoly grid operators in China in the SG deployment. While our analysis confirms the findings of existing SG literature that incumbent actors may assume important roles as network operators (Cossent *et al.*, 2009; Nepal *et al.*, 2014; Pollitt, 2010) and standard setters (Pullinger *et al.*, 2014), we have also highlighted the roles of infrastructural enablers, technology developers, and new energy service providers – roles that have been largely missing from the literature. In addition, we critically assessed the role of the two incumbents as a fundamental block to regime changes that are required to realize higher-orders of SG benefits. Our findings confirm with the western literature that problems associated with excessive reliance on incumbents and utility disincentives also apply in the Chinese context (see, for example, Brunekreeft *et al.*, 2015; Martinot & McDoom, 2000).

Thirdly, our study has contributed to the SG literature on innovation in stakeholder relationships. Our findings provided insights to the emergence of new stakeholder relationships as SG develops, as well as the potential and limits of incumbents in facilitating SG deployment (Laes *et al.*, 2014; Mah *et al.*, 2013; Markard & Truffer, 2006). The manner in which the two grid operators have limited interactions and weak linkages with distributed energy suppliers and electricity consumers has constrained China's attainment of higher-order SG benefits including large scale deployment of distributed energy generation and demand responses programmes.

Fourthly, the impacts of the partial, incomplete, electricity market reforms on the motivations and incentives of the two grid operators to engage in SG deployment are of particular significance. This finding contributes to the literature that discusses the extent to which, and how, market liberalization acts as a driver for radical changes in energy socio-technical regimes (see for example (Anuta *et al.*, 2014; Arocena, 2000; Markard & Truffer, 2006))**.**

Our findings have various policy implications. SG deployment in China requires innovation in stakeholder relationships. The first policy implication relates to the need for innovation in regulating incumbent utilities. Our study demonstrates that the problem of incumbents' disincentives has undermined the effectiveness of the Chinese model. A growing body of literature and empirical data has suggested that innovation in regulatory frameworks can provide utilities with incentives to become distributed network operators for renewable sources (Connor *et al.*, 2014; Mah *et al.*, 2014). New York City, for example, has introduced earning adjustment mechanisms by providing utility incentives to achieve peak reductions, and facilitate interconnection of DE sources (Mitchell, 2016). The Chinese government can assume a much more important role in regulating SG developments. Institutional changes and market transformation that are critical to enable SG deployment are areas which have yet to receive sufficient policy attention. The government needs to strengthen its regulatory systems in such a way that incumbent grid companies are provided with incentives to serve as distribution system operators, to plan and operate distributed grids, and to facilitate the entry of new DE electricity suppliers into the market.

Such regulatory systems are also required to protect the interests of new market players, such as electricity suppliers of DEs and prosumers. Non-state actors require strong regulatory and policy support in order to grow in influence and challenge the status quo. The NDRC and State Electricity Regulatory Commission (SERC), the regulators of China's electricity sector, needs to be more determined in regulating, firstly, which parts of the transmission and distribution network systems can be opened up to competition, and, secondly, which players should be subject to regulation.

Secondly, sufficient attention should be given to the negative consequences of relying on incumbent utilities in assuming functions that are public service in nature. There is a need to engage independent third parties or industrial associations in China's SG deployment. The slow progress in standard-setting which has impeded the uptake of DE in China is a good example. Although the 2012 SGCC's utility-level regulation which permits direct sales of electricity from generators to other users was a milestone of DE regulation, it took the NEA of NDRC two more years to introduce a corresponding national regulation for DPV in 2014 (Interviews BJ/01/2014; BJ/04/2014). Such an incumbent-led approach for standard-setting has provided opportunities for the incumbents to prevent new market players from entering the market (Interviews BJ/01/2014; BJ/04/2014).

It is important to note that some governments, for example, in the US, have reached out to industrial associations, leaving this important task of standard-setting to civil society. In the US, the National Institute of Standards and Technology (NIST), an agency of the U.S. Department of Commerce has been collaborating actively with SG stakeholders, particularly industrial associations, in order to develop SG standards and protocols in a timely and efficient manner (NIST, 2013). The Chinese government might therefore explore the role played by industrial associations such as the China Electricity Council (中国电力企业联合会), a major industrial association of China's power enterprises and institutions, in coordinating and facilitating standardization of Chinese SG technologies.

Our findings are based on a single case study which is country and technology-specific. However, they can be generalized to other countries, such as France, Japan, and South Korea, where incumbent utilities still assume a central role in electricity markets (Mah *et al.*, 2012; Mamo, 2010). Further research on a comparative study of China and these countries may improve the generalizability of these findings. This study has not be able to explore in any detail the changing relations between incumbents and niche actors, such as real estate developers and prosumers in China. A growing body of literature has however examined interactional incumbent-challenger relationships, the tensions that emerge, and the associated impacts on sustainable energy transitions (see, for example, (Betsill & Stevis, 2016)).

Such an investigation in the Chinese context or from a comparative perspective should be the focus of future studies.

Appendix: List of interviewees

21 interviewees were interviewed in 14 interview meetings; in some meetings, there were two or more than two interviewees.

Code	Background of interviewee	Date of interview	Format of interview
BJ/01/2014	A senior executive of an energy-related consulting company, Beijing	23 July, 2014	FI
BJ/02/2014	A middle-rank consultant of an energy-related consulting company, Beijing	23 July, 2014	FI
BJ/03/2014	A Senior executive of the State Grid Energy Research Institute of SGCC	23 July, 2014	FI
BJ/04/2014	A senior government official in the Department of Renewable and New Energy, NDRC	23 July, 2014	FI
BJ/05/2014	A senior advisor in Energy Research Institute of NDRC	24 July, 2014	FI
BJ/06/2014	A researcher in Guangzhou Institute of Energ Conversion, Chinese Academy of Sciences	24 July, 2014	FI
BJ/07/2014	A senior executive in State Grid Energy Research Institute of SGCC	24 July, 2014	FI
BJ/08/2014	A middle rank executive in State Grid Energy Research Institute of SGCC	24 July, 2014	FI
TJ/01/2014	A professor in the School of Elecrical Engineering & Automation of Tianjin University	25 July, 2014	FI
TJ/02/2014	A researcher in the School of Elecrical Engineering & Automation of Tianjin University	25 July, 2014	FI
TJ/03/2014	A senior executive in a green building research institute in Tianjin	25 July, 2014	FI
GD/01/2015	A senior executive in Guangzhou	7 January, 2015	FI

	Institute of Energy Conversion, Chinese Academy of Sciences		
GD/02/2015	A researcher in Guangzhou Institute of Energy Conversion, Chinese Academy of Sciences	7 January, 2015	FI
GD/03/2015	A senior executive in Smart Grid Institute of CSG *updated data was provided by the interviewee through email correspondence, dated 12 May, 2016	7 January, 2015	FI/EC
GD/04/2015	A researcher in Smart Grid Institute of CSG	7 January, 2015	FI
GD/05/2015	A researcher in Smart Grid Institute of CSG	7 January, 2015	FI
GD/06/2015	A middle-rank executive of a solar technology company in Zhuhai	14 March,2015	FI
GD/07/2016	A professor at The Lab of Solar PV and Mico-grid Applied Technology, Guangzhou Institute of Energy Conversion, Chinese Academy of Sciences	3 March, 2016	FI
GD/08/2017	A senior executive in Foshan Power Supply Bureau, Guangdong Power Grid Corporation, CSG	24 March, 2017	FI
GD/09/2017	An officer in Foshan Power Supply Bureau, Guangdong Power Grid Corporation, CSG	24 March, 2017	FI
GD/10/2017	A project manager, a solar energy company in Foshan	24 March, 2017	FI

*In order to keep our interviewees anonymous, this study indicates interviews by number. The first two letters indicate the location (BJ for Beijing, TJ for Tianjin, and GD for Guangdong), the two digits indicate the interview numbers, followed by the year of interviews. The interview formats included face-to-face interview (FI) and email correspondence (EC).

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Table 1: Chronology of SG policy developments in China

2009	SGCC announced a Three-Stage SG plan (2009-2020). Stage 1 (2009-10): Initial planning and piloting, where the master plan and selected pilot projects are created and put into action; Stage 2 (2011-15): Comprehensive construction involving breakthroughs in key technology and equipment for achieving extensive application; and Stage 3 (2016-20): Upgrading, enhancing, and optimizing grid performance with respect to resource allocation, security, and efficiency, interplay among power grid, power generation and customers (Xu, Xue, & Wong, 2014; Yuan et al., 2014)
2010	CSG announced a Two-Stage SG plan. Stage 1 (2012-2013) involves planning, research and demonstration. Stage 2 (2012 and after) involves demonstration and implementation (Yuan et al., 2014).
2010	The then Chinese Premier Wen Jiabao announced that construction of a SG as a national priority, with completion planned for 2020 (EIA/SAIC, 2011).
2011	The 12th Five-year Plan of National Economic and Social Development included “advancing SGs” as a key task for delivering power system transition, indicating that SG has been included in China’s national

	energy policy (Yuan et al., 2014).
2012	NDRC announced a special plan titled “Special Planning of 12th Five-Year Plan (2011-15) on Smart Grid Major Science and Technology Industrialization Projects”, which aims to acquire key SG technologies, formulate an independent technology and standard system for SG, as well as integrated supply chain; and complete the construction of modern SGs. It also includes over 75 SG-related demonstration and industrial projects at different levels (MIT, 2012; Yuan et al., 2014)
2015	NDRC and NEA jointly announced the Guiding Suggestion on Boosting Smart Grid Development (NDRC & NEA, 2015) which aims for the initial completion of a national SG system by 2020, with supporting measures in technical assistance, mutual complementarity of renewable energy sources, IT and cloud systems, disaster response and economic viability, international standardization, encouraging new business model development.
2016	In February 2016, NDRC, NEA, and Ministry of Industry and Information Technology jointly announced “The Guiding Opinion Regarding the Carrying Out of "Internet" and Smart Energy

	Development". This Opinion highlighted the development of the internet of energy through advanced metering infrastructure and other assisting infrastructure by measuring real-time energy consumption. It also highlighted the importance of regulating an advanced metering infrastructure network in order to realize a safe, reliable, and rapid bi-directional utility-end user communication (NDRC, NEA, & MITT, 2016).

Figure 1: The geographical coverage of SGCC and CSG
(Source: St. John (2014))

Table 2. Basics of SGCC and CSG

	SGCC	CSG
Geographical scope	▪ It serves 26 provinces (including autonomous regions and direct-controlled municipalities), with the exception of South China. ▪ It covers 88 % of China's territory, over 1.1 billion people ▪ It provides electricity that meets 83 % of national power consumption ▪ It includes five regional grids: Northwestern Grid, North Grid, Northeastern Grid, Central Grid, and East Grid	▪ It serves 5 Southern Provinces: Guangdong, Guangxi, Yunnan, Guizhou and Hainan ▪ Electrical transmission and distribution covers 12 % of China's territory, serving roughly 230 million people, and 72.92 million clients. ▪ It provides electricity that accounts for 17 % of the national power consumption

On-grid total Installed capacity (2014)	1049 GW	246 GW
On-grid Energy mix (2014)	Thermal – 740 GW (70.5%) Hydro – 199 GW (19.0%) Wind – 75 GW (7.2%) Solar Photovoltaic – 22 GW (2.1%) Nuclear – 13 (1.2%)	Thermal Power – 127 GW (51.6%) Hydro Power – 103 GW (41.9%) Wind Power – 8 GW (3.3%) Nuclear Power – 7 GW (2.8%) Solar Photovoltaic and Others (Biomass, waste, geothermal) – 1 GW (0.4%)

(Sources: Geographical scope – (Brunekreeft *et al.*, 2015; Ma and He, 2008; SGCC, 2015a; Zpryme, 2011); installed capacity and energy mix - (CSG, 2015a; SGCC, 2015a; Interview GD/03/2015)).

Table 3. An assessment of China's SG developments

Orders of SG Development	Indicators	Our assessment	Illustrative examples
First-order transformation	▪ Visions and policy strategies are in place. ▪ But business cases not in place and benefits (including operational, customer and societal benefits) of smart grids are not realized.	●	• SG plans and policy initiatives are in place. • Approximately 190 million smart meters have been installed, representing about 80 percent penetration rate in China (Interview BJ/03/2014). But the functional benefits of web-based data visualization and two-way utility-end user communication have not been realized (Interview BJ/01/2014). • The two grid companies have conducted a large number of DR pilots in order to test customers' responses. However, these pilots were superficial in nature, to a large extent because there is a lack of a functioning dynamic pricing system which could have

			realized the functional benefits of DR programmes (Interview BJ/03.2014). A DR pilot in Foshan, Guangdong Province, conducted by CSG offered economic compensation for industrial end users but was not able to offer such compensation beyond that pilot project (Interview GD/03/2015). • In China, DE sources which include distributed photovoltaic, small hydropower, distributed wind generation, and natural gas distributed energy (Zeng et al., 2015a, b) amounted to 34.36 GW (approximately 3 percent of the national total installed capacity) (in 2012) (Figure 2) (CNREC, 2013; SGCC, 2012). Most of these DE comes from hydropower while solar PV, wind, and other DE sources remain limited in scale (Figure 3). • BM developments are slow, and mostly at the pilot scale. Most SG pilots aim to overcome technical challenges, with a negligible number of pilots experimenting in BMs

			(Interview GD/03/2015). One of the exceptions include a recent pilot project conducted in Foshan, Guangdong, which tries to involve insurance companies in order to mitigate market risks associate with solar PV projects (Guangdong DRC, 2014).
Second-order transformation	▪ Business cases are emerging and investments are being made. ▪ Operational benefits are realized but not customer and societal benefits. But some applications for particularly markets are validated. ▪ Operational linkages are established between two or more technological	○	Changes in business models and regulatory arrangements are not noticeable in China

	aspects of smart grid; cross-functional benefits are achieved; partnerships are cultivated. ▪ Some minor regulatory changes such as new incentive systems for smart meter installations are introduced, mostly in pilot scale. But major regulatory changes involving tariff structure and market structure are not introduced.		
Third-order transformation	▪ Smart grid functionality and benefits (including operational, customer and	○	

	societal benefits) are realized. ▪ New business models are economically sustainable. New products, services and markets are created. ▪ Major regulatory changes involving tariff structure and market structure are also introduced.		

●: Strong evidence

◐: Moderate evidence

○: Indiscernible evidence

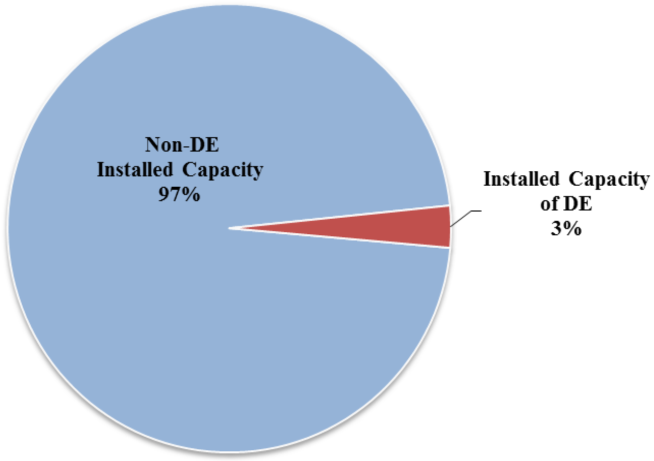

Figure 2. Installed capacity of DE in China (2012) (Source: by Authors; primary data from (CNREC, 2013a; SGCC, Dec 10, 2012))

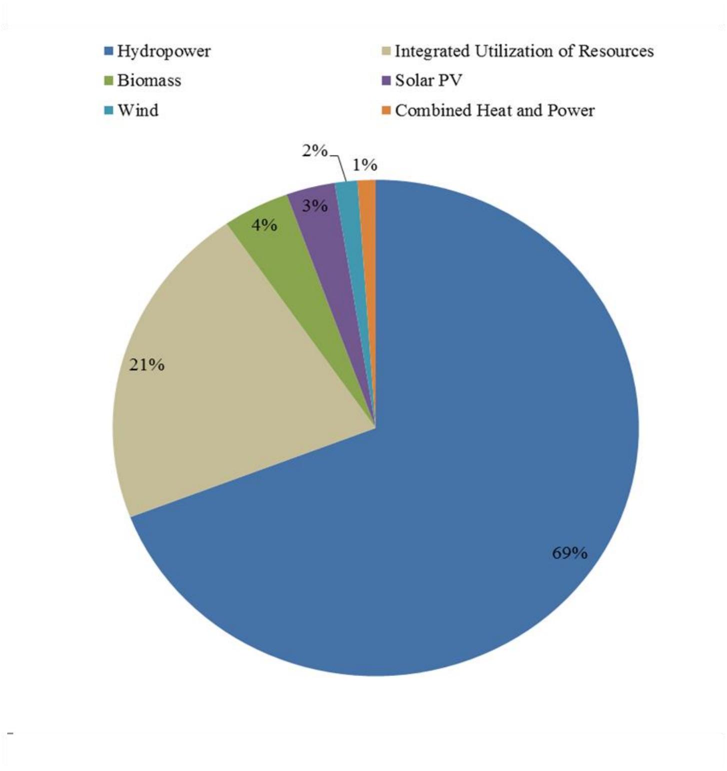

Figure 3. Installed capacity of DE by types in China (2012) (Source: by Authors; primary data from (CNREC, 2013a; SGCC, Dec 10, 2012))

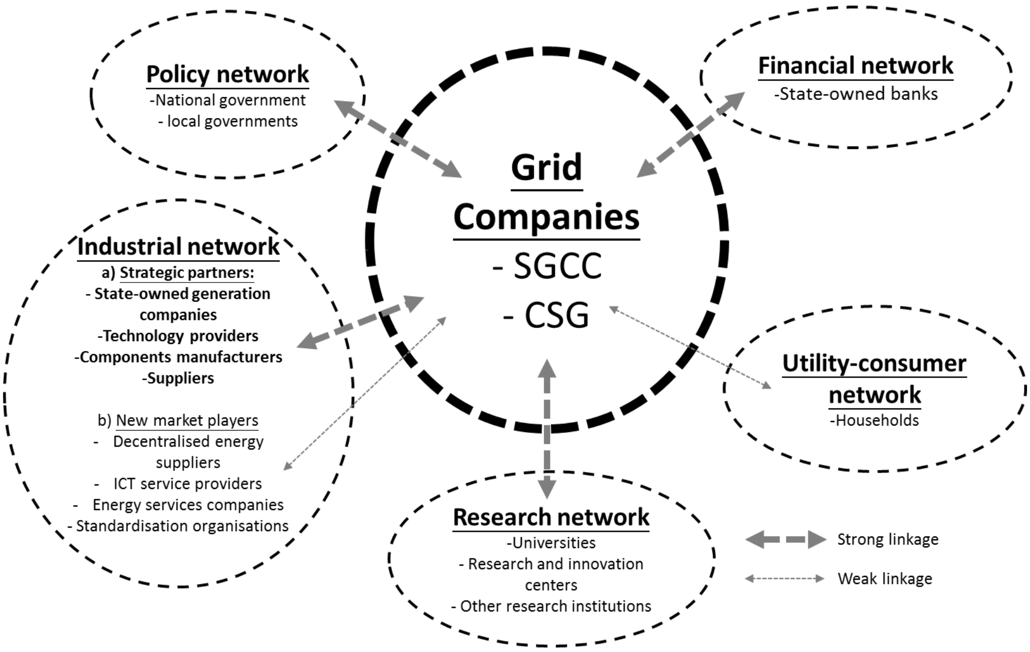

Figure 4. Networks between SGCC, CSG and other SG stakeholders in China (Source: Authors)